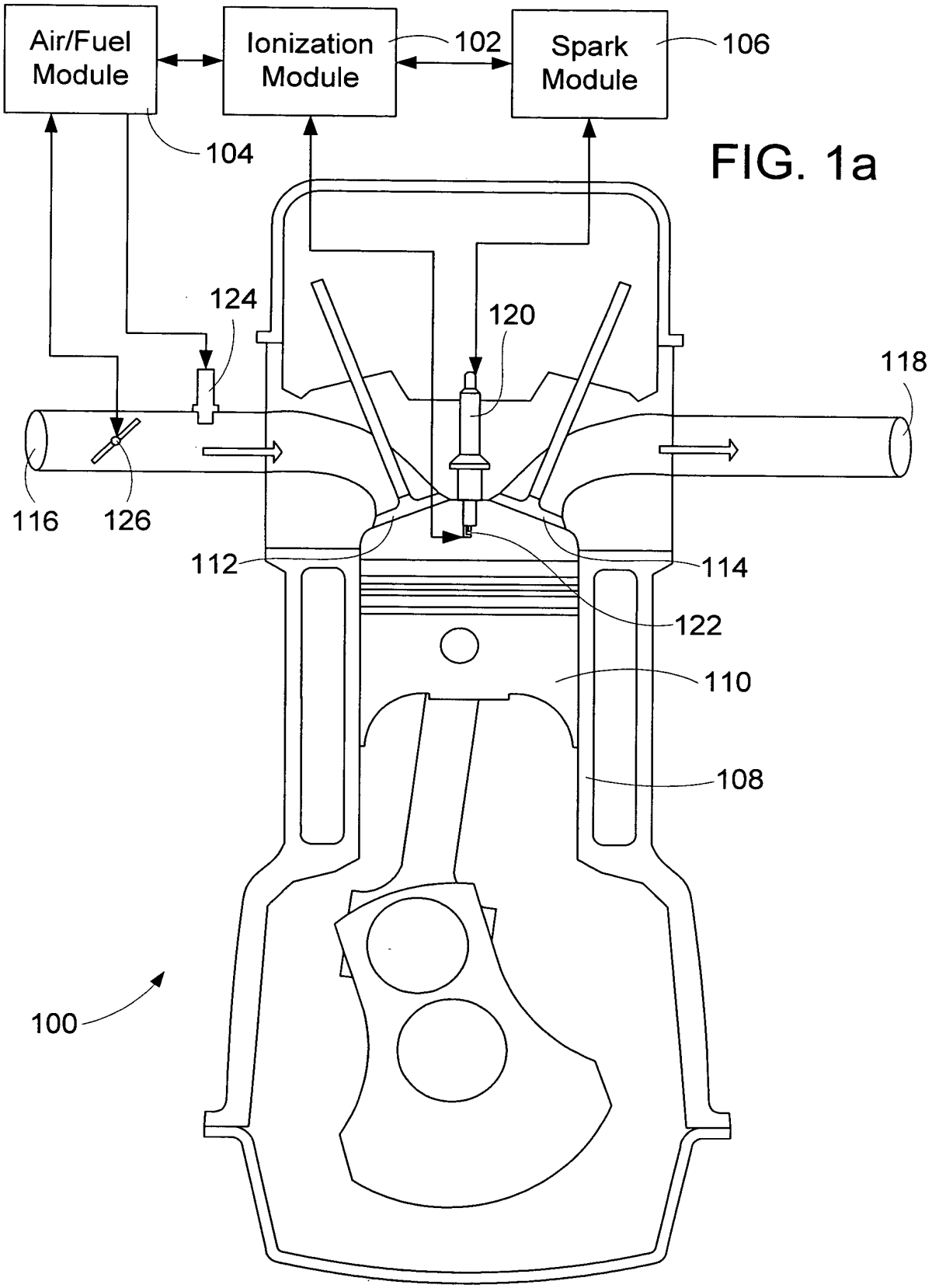

Air/Fuel Module
Ionization Module
102
Spark Module
106
104
124
120
118
116
126
112
114
122
110
108
100

FIG. 1a

FIG. 1b

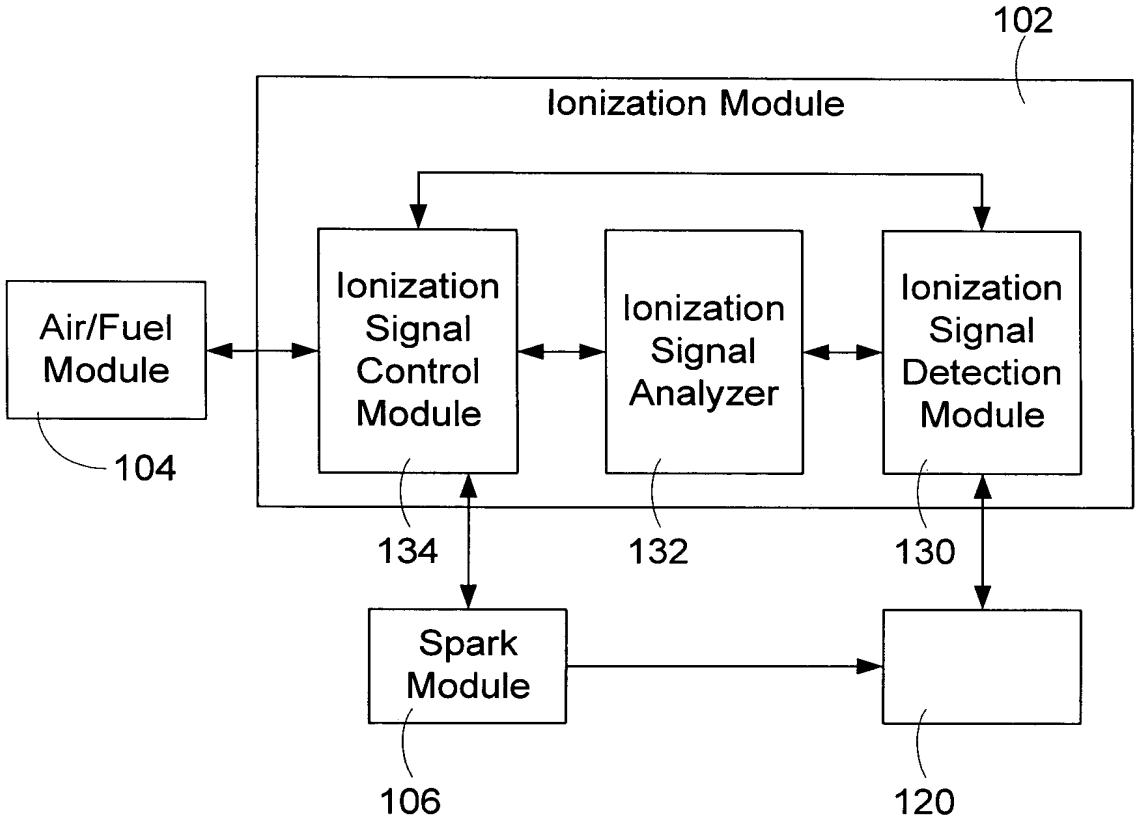

102
Ionization Module
Air/Fuel Module
104
Ionization Signal Control Module
Ionization Signal Analyzer
Ionization Signal Detection Module
134
132
130
Spark Module
106
120

FIG. 2

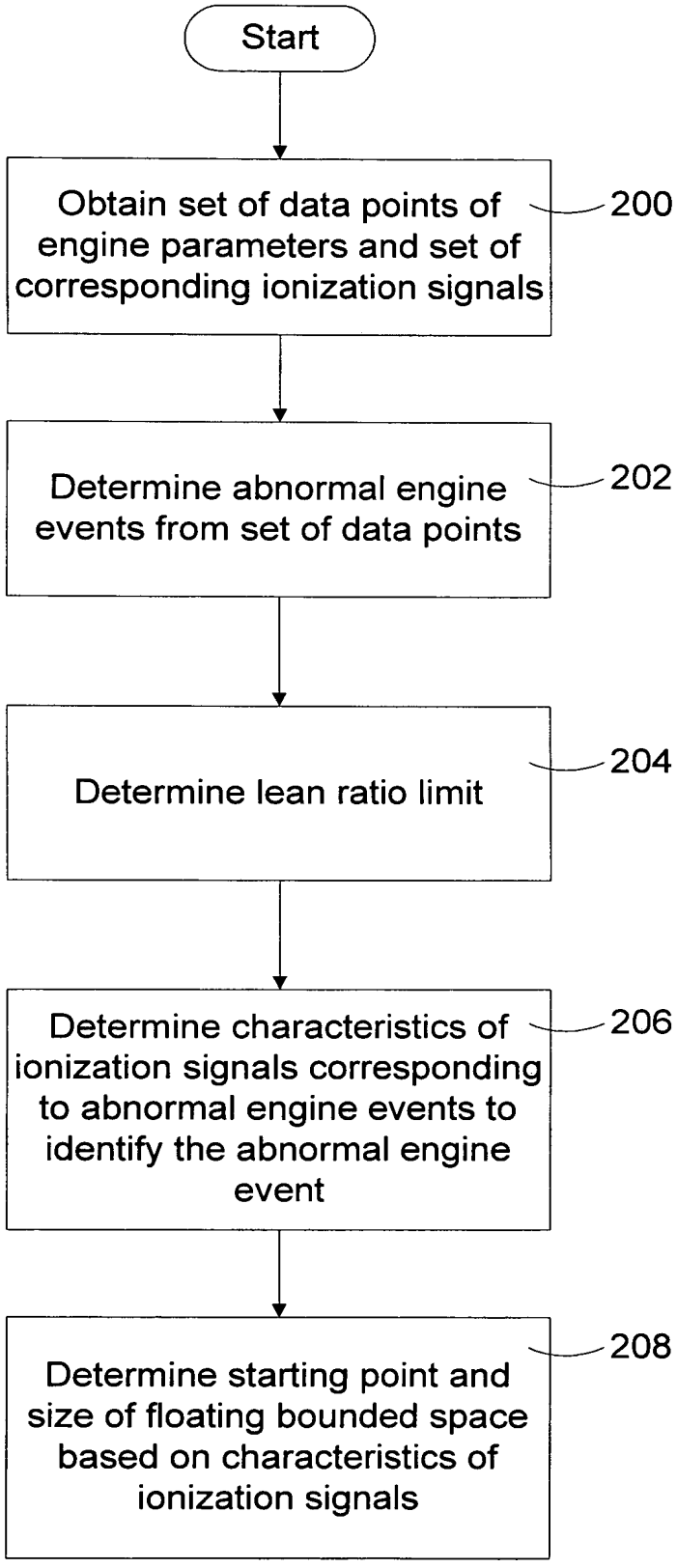

Start
Obtain set of data points of engine parameters and set of corresponding ionization signals
200
Determine abnormal engine events from set of data points
202
Determine lean ratio limit
204
Determine characteristics of ionization signals corresponding to abnormal engine events to identify the abnormal engine event
206
Determine starting point and size of floating bounded space based on characteristics of ionization signals
208

FIG. 3a

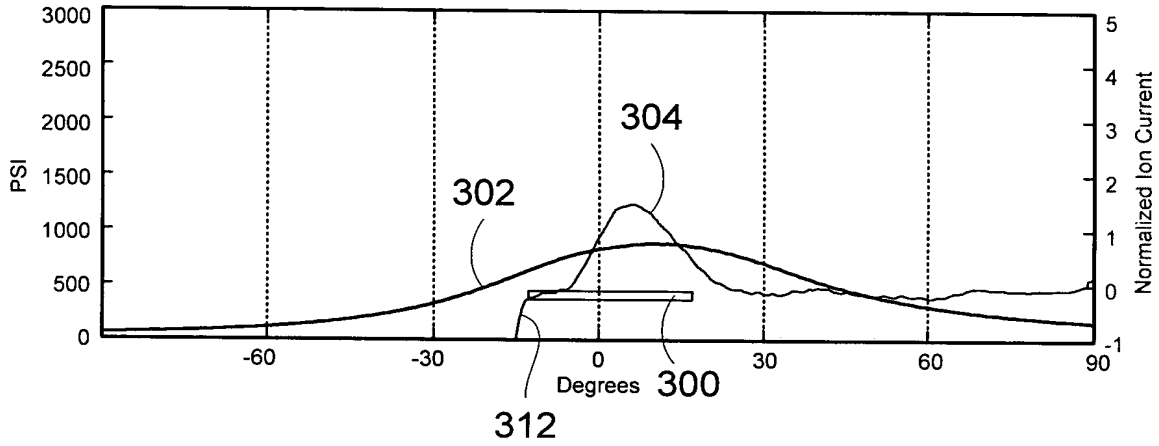


FIG. 3b

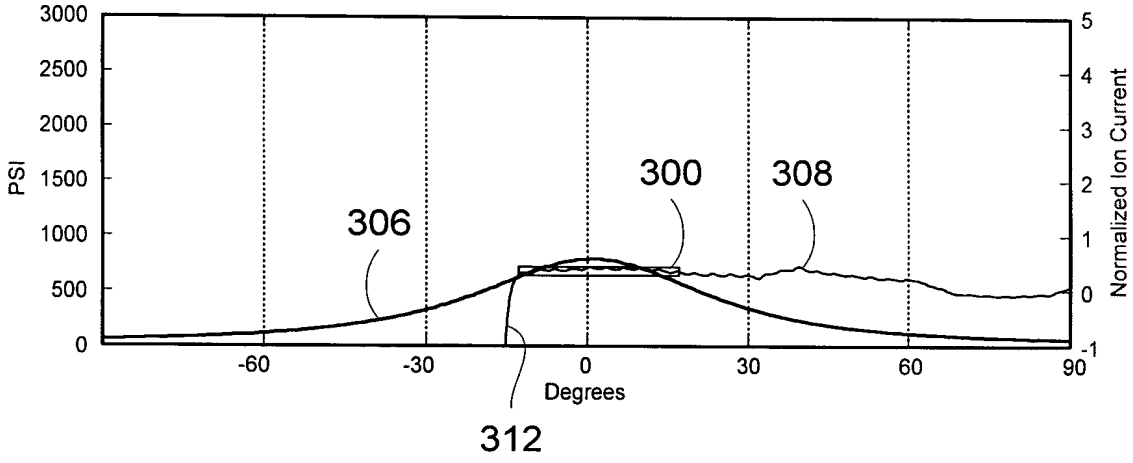


FIG. 3c

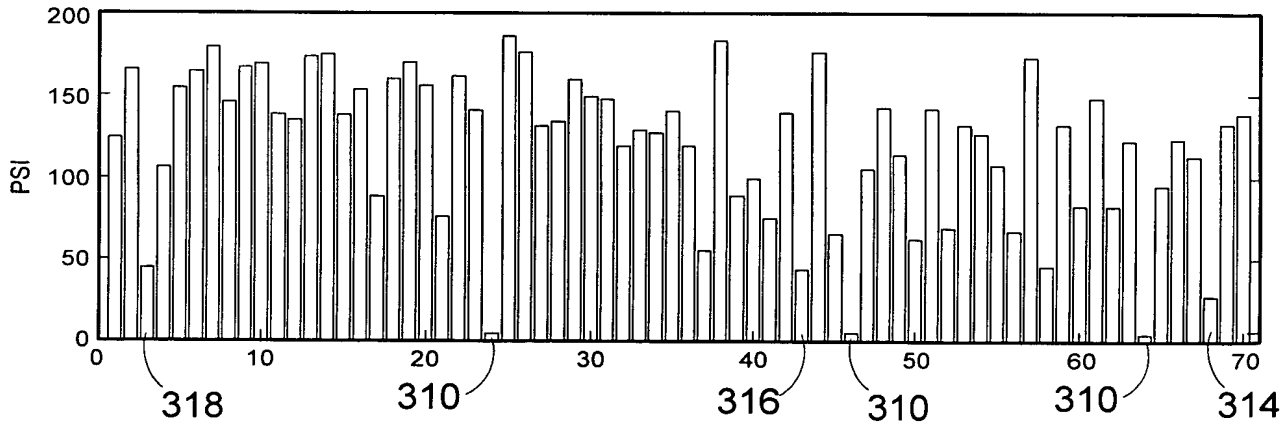


FIG. 4a

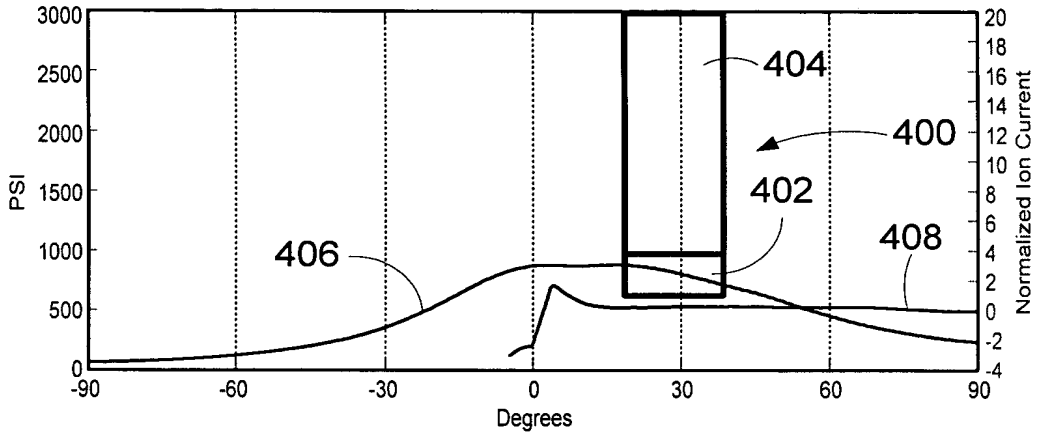

3000
2500
2000
1500
1000
500
0
PSI
-90
-60
-30
0
30
60
90
Degrees
20
18
16
14
12
10
8
6
4
2
0
-2
-4
Normalized Ion Current
404
400
402
408
406

FIG. 4b

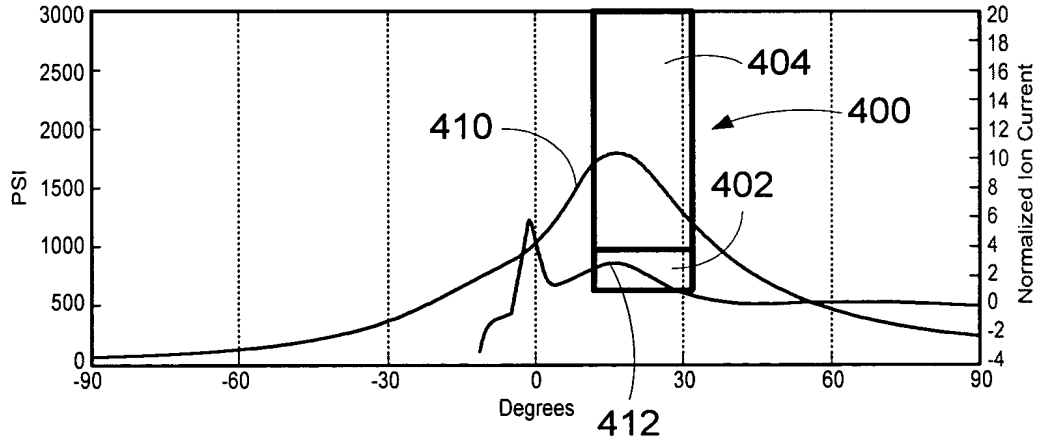

3000
2500
2000
1500
1000
500
0
PSI
-90
-60
-30
0
30
60
90
Degrees
20
18
16
14
12
10
8
6
4
2
0
-2
-4
Normalized Ion Current
404
400
410
402
412

FIG. 4c

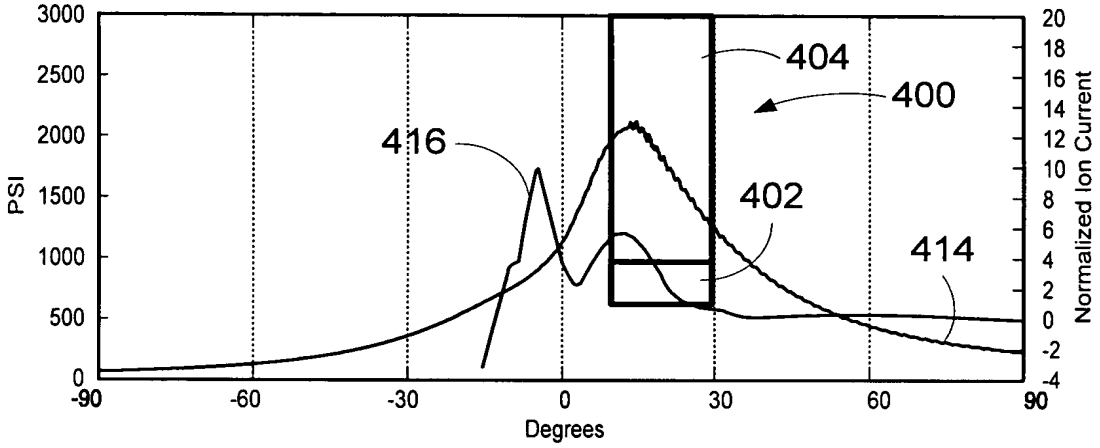

3000
2500
2000
1500
1000
500
0
PSI
-90
-60
-30
0
30
60
90
Degrees
20
18
16
14
12
10
8
6
4
2
0
-2
-4
Normalized Ion Current
404
400
416
402
414

FIG. 4d

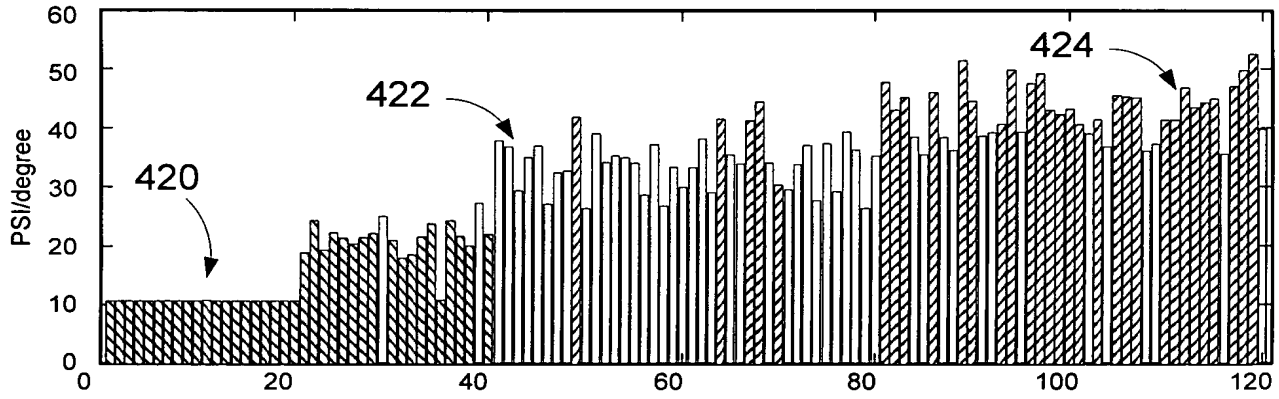

60
50
40
30
20
10
0
PSI/degree
0
20
40
60
80
100
120
420
422
424

FIG. 5a

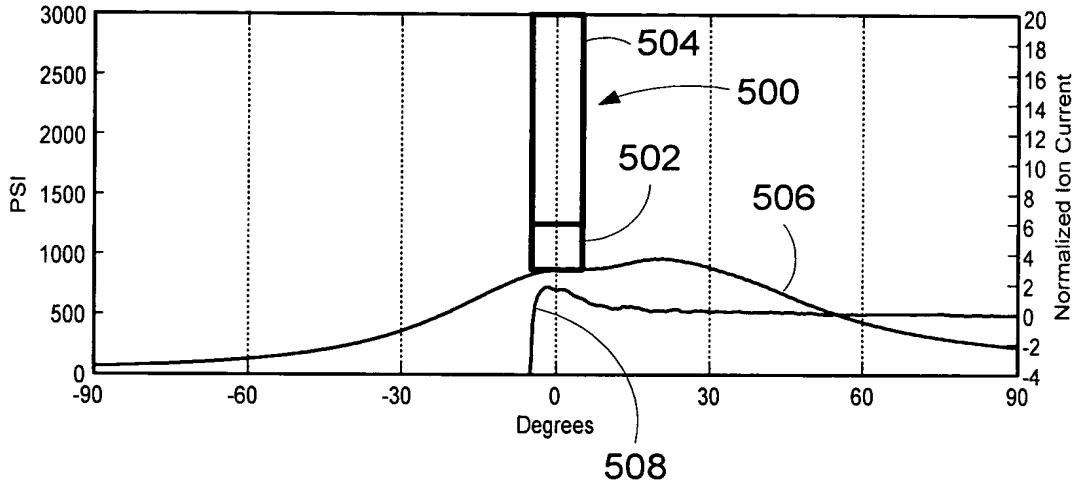

3000
2500
2000
1500
1000
500
0
PSI
-90
-60
-30
0
30
60
90
Degrees
20
18
16
14
12
10
8
6
4
2
0
-2
-4
Normalized Ion Current
504
500
502
506
508

FIG. 5b

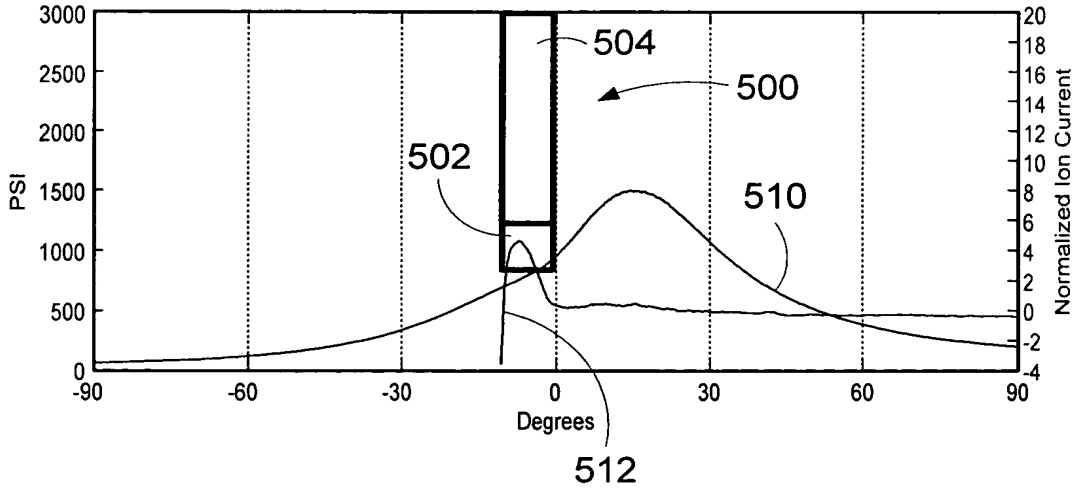

3000
2500
2000
1500
1000
500
0
PSI
-90
-60
-30
0
30
60
90
Degrees
20
18
16
14
12
10
8
6
4
2
0
-2
-4
Normalized Ion Current
504
500
502
510
512

FIG. 5c

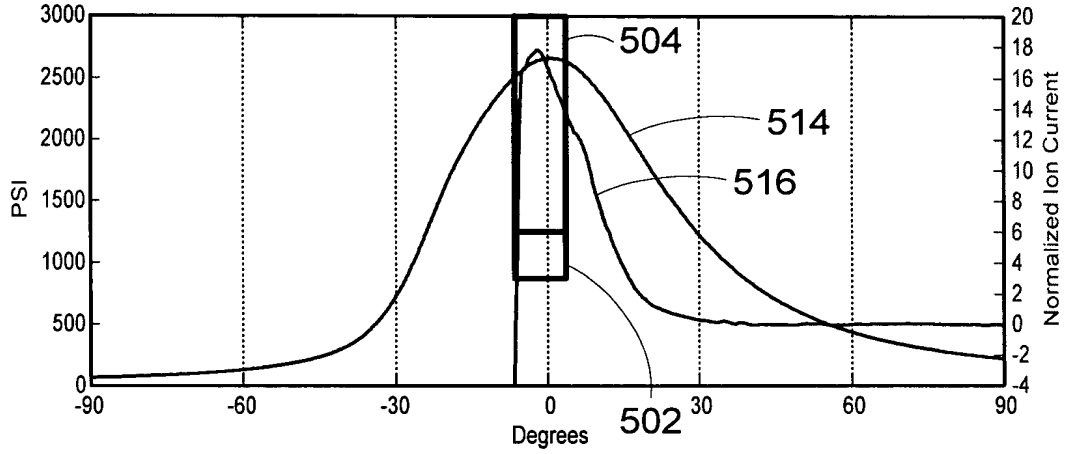

PSI
Normalized Ion Current
Degrees
504
514
516
502
3000
2500
2000
1500
1000
500
0
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-90
-60
-30
0
30
60
90

FIG. 5d

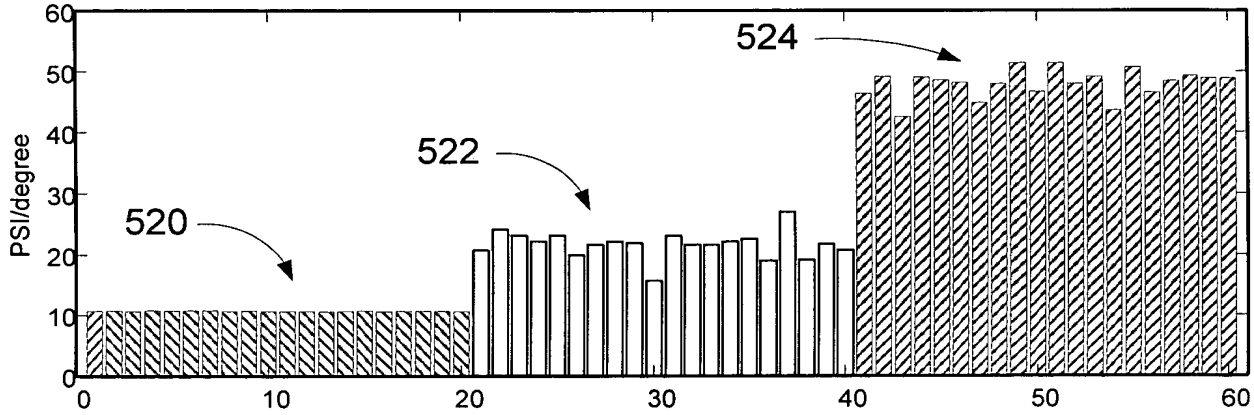

PSI/degree
520
522
524
60
50
40
30
20
10
0
0
10
20
30
40
50
60

FIG. 6a

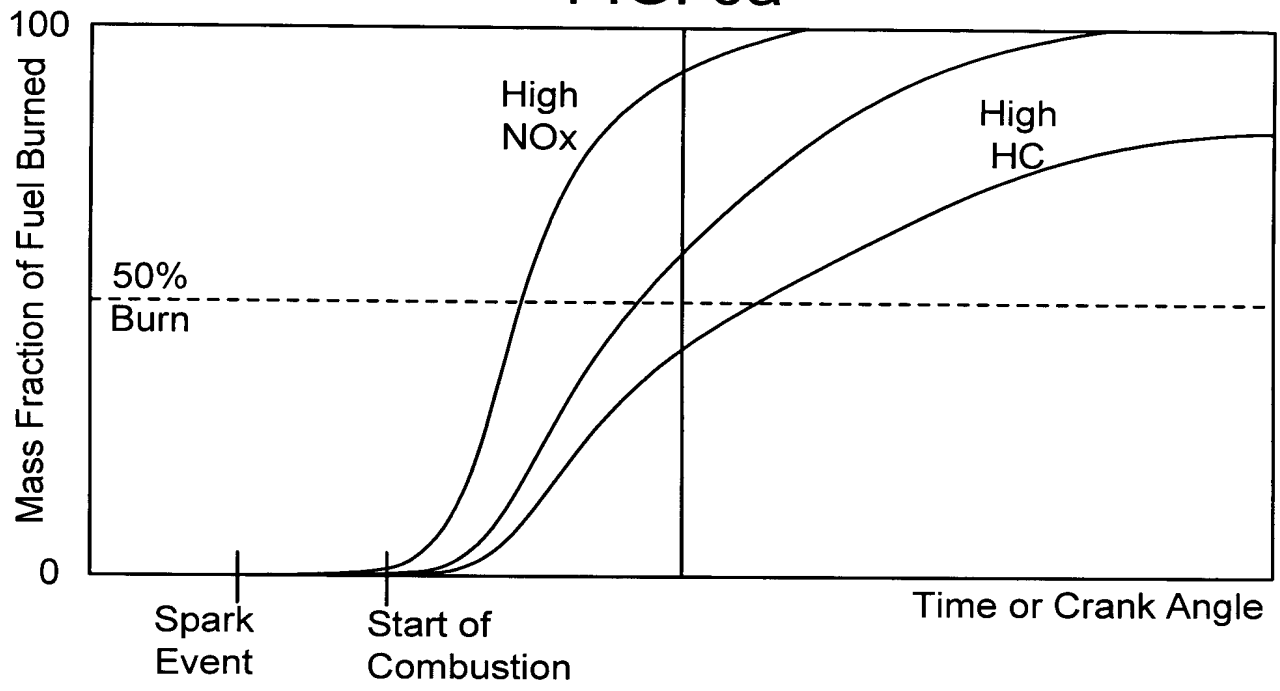

100
Mass Fraction of Fuel Burned
0
High
NOx
High
HC
50%
Burn
Spark
Event
Start of
Combustion
Time or Crank Angle

FIG. 6b

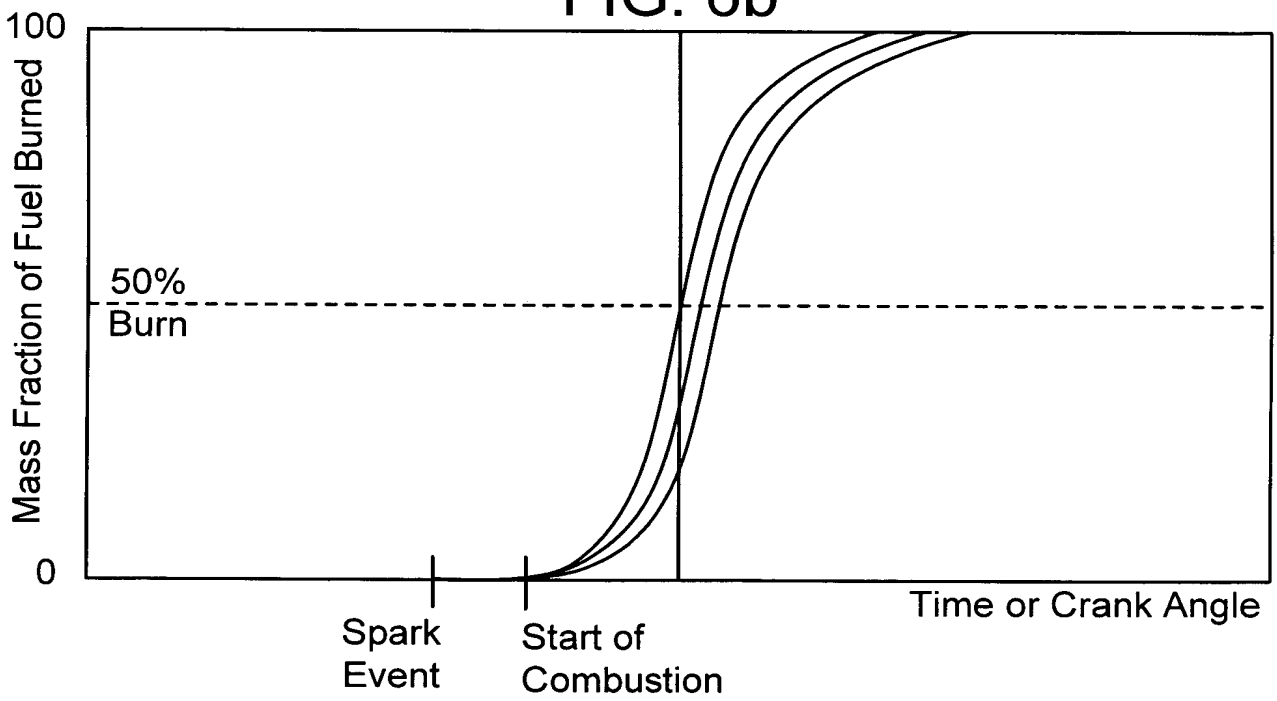

100
Mass Fraction of Fuel Burned
0
50%
Burn
Spark
Event
Start of
Combustion
Time or Crank Angle

FIG. 7

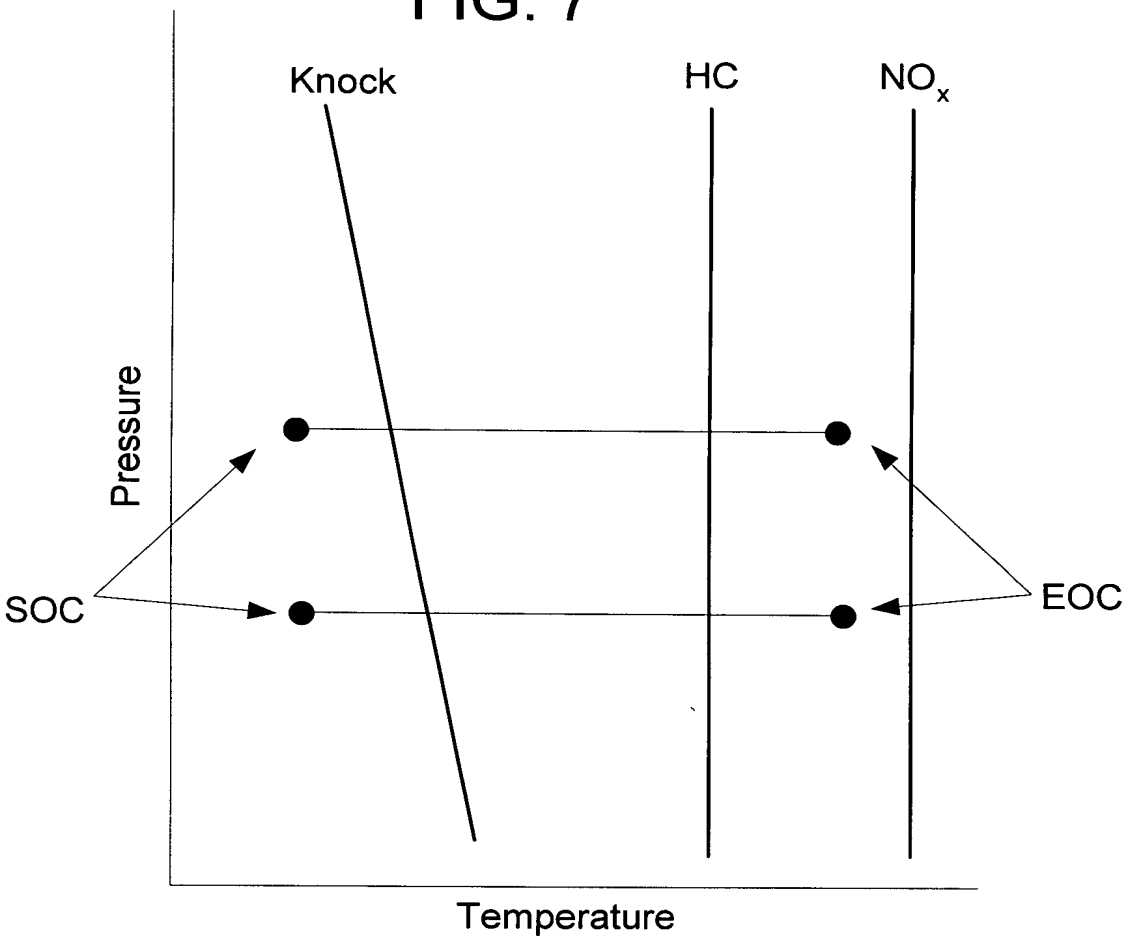

Knock
HC
NO_x
Pressure
SOC
EOC
Temperature

FIG. 8

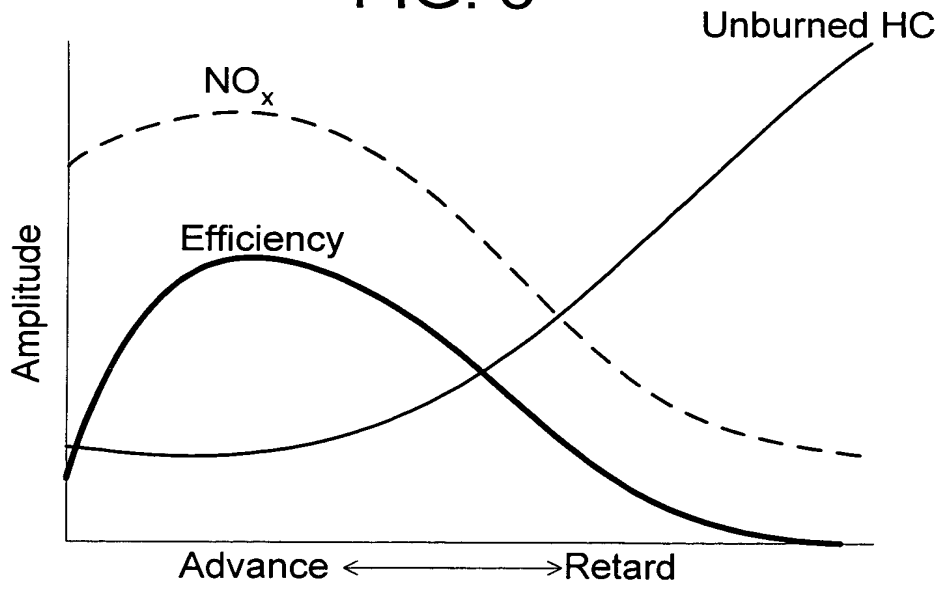

Unburned HC
NO_x
Efficiency
Amplitude
Advance ⟷ Retard
50% Burn Rate Point

FIG. 9

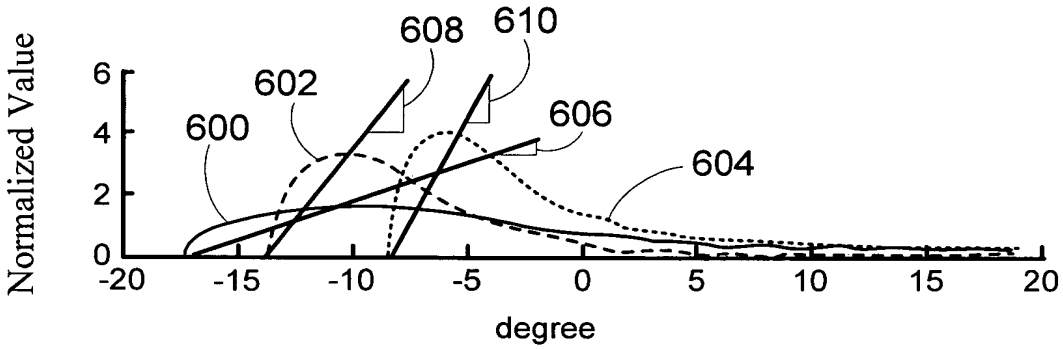

Normalized Value
608
610
602
606
600
604
6
4
2
0
-20
-15
-10
-5
0
5
10
15
20
degree

FIG. 10

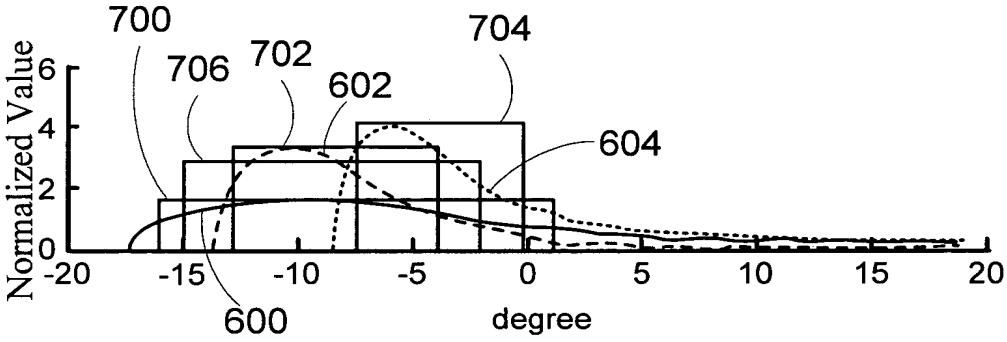

700
704
706
702
602
604
Normalized Value
6
4
2
0
-20
-15
-10
-5
0
5
10
15
20
600
degree

FIG. 11

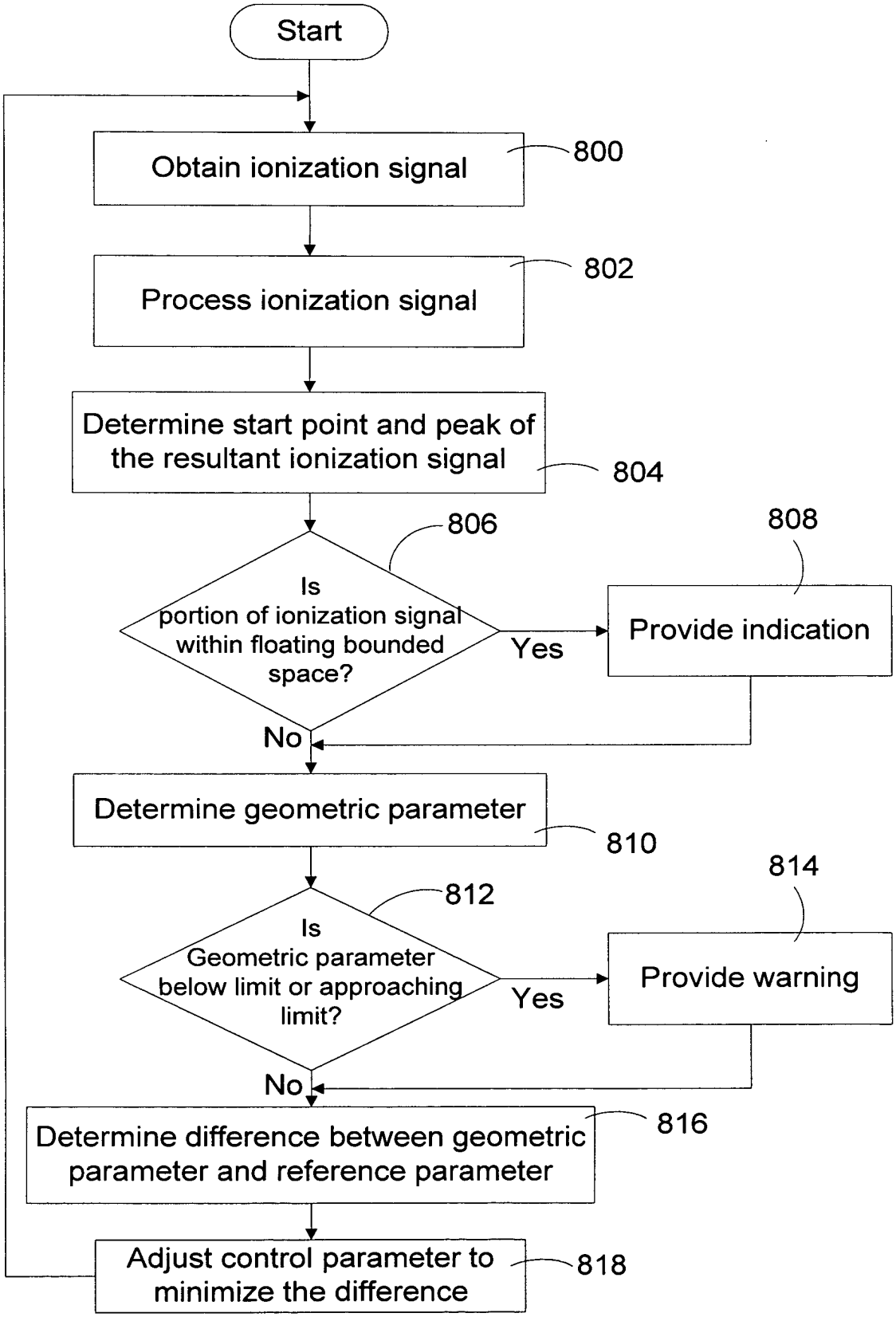

Start
Obtain ionization signal
800
Process ionization signal
802
Determine start point and peak of the resultant ionization signal
804
806
Is portion of ionization signal within floating bounded space?
Yes
808
Provide indication
No
Determine geometric parameter
810
812
Is Geometric parameter below limit or approaching limit?
Yes
814
Provide warning
No
Determine difference between geometric parameter and reference parameter
816
Adjust control parameter to minimize the difference
818

FIG. 12

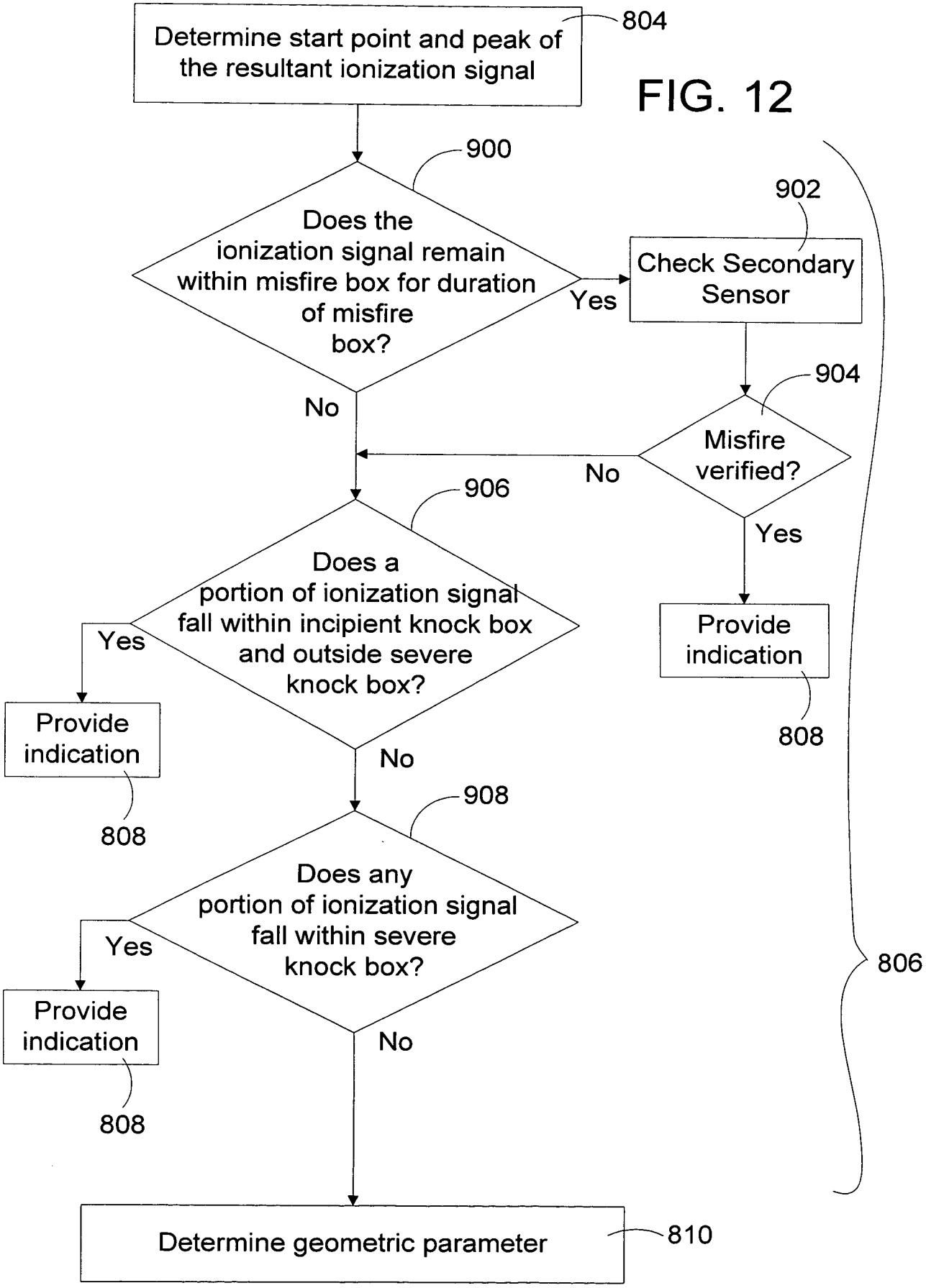

Determine start point and peak of the resultant ionization signal
804
900
Does the ionization signal remain within misfire box for duration of misfire box?
Yes
902
Check Secondary Sensor
No
904
Misfire verified?
No
Yes
906
Does a portion of ionization signal fall within incipient knock box and outside severe knock box?
Yes
Provide indication
808
No
Provide indication
808
908
Does any portion of ionization signal fall within severe knock box?
Yes
Provide indication
808
No
806
Determine geometric parameter
810

FIG. 13

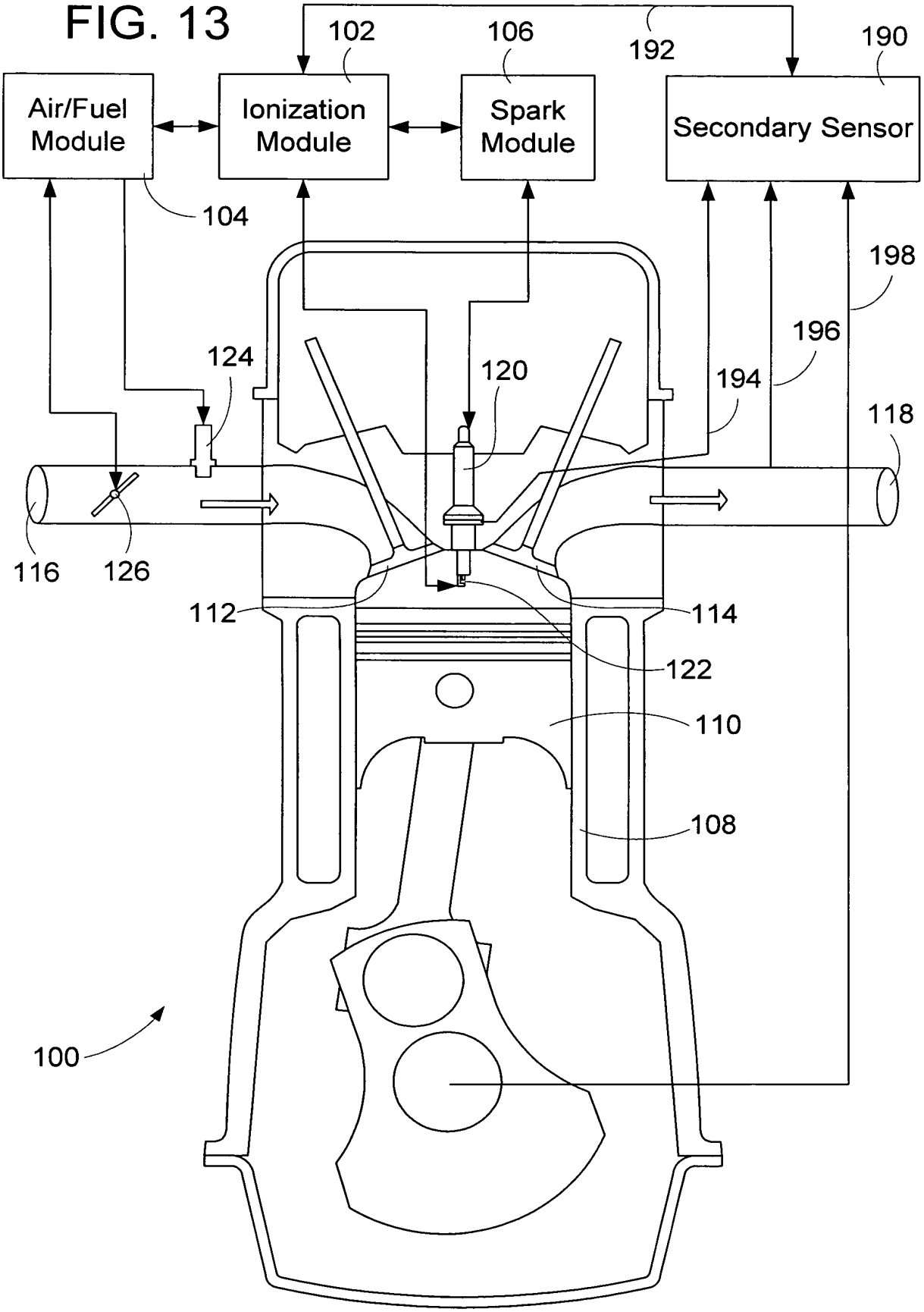
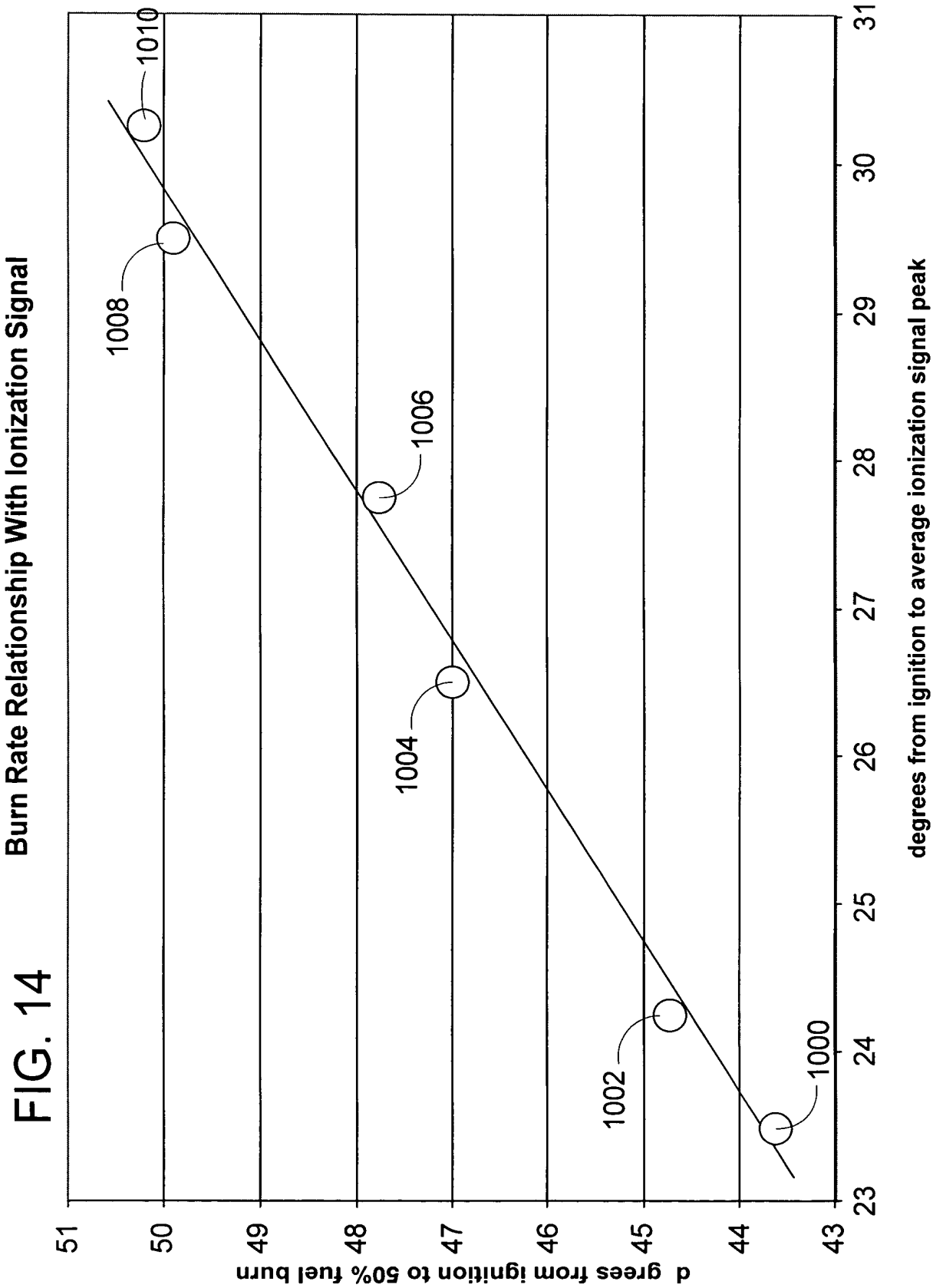

Air/Fuel Module
Ionization Module
Spark Module
Secondary Sensor
102
106
192
190
104
198
196
124
120
194
118
116
126
112
114
122
110
108
100

FIG. 14


Burn Rate Relationship With Ionization Signal
d grees from ignition to 50% fuel burn
degrees from ignition to average ionization signal peak
51
50
49
48
47
46
45
44
43
31
30
29
28
27
26
25
24
23
1010
1008
1006
1004
1002
1000

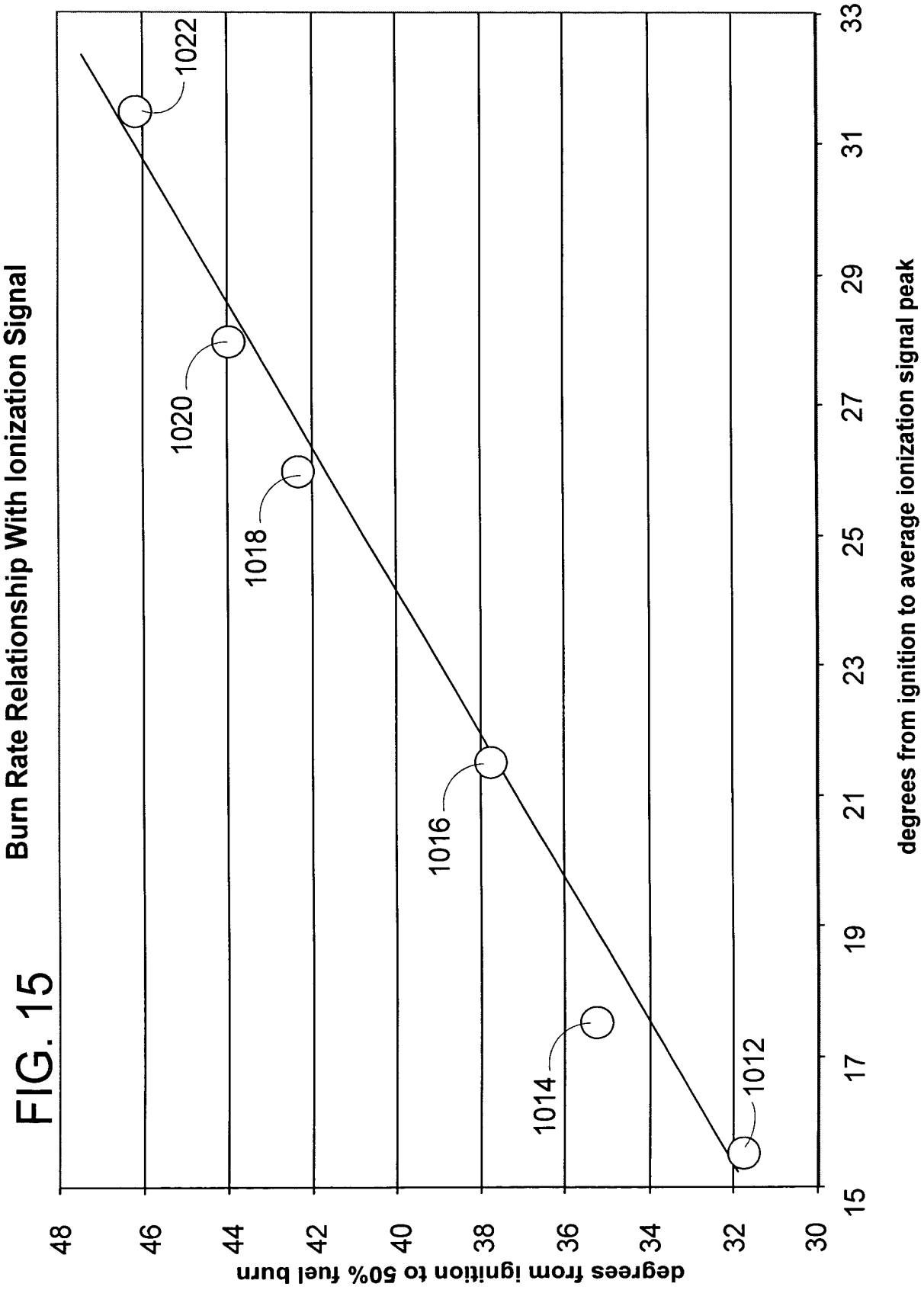

Burn Rate Relationship With Ionization Signal
1022
1020
1018
1016
1014
1012
48
46
44
42
40
38
36
34
32
30
degrees from ignition to 50% fuel burn
15
17
19
21
23
25
27
29
31
33
degrees from ignition to average ionization signal peak

FIG. 15